APPENDIX I

Design Guidelines for Slope Tapered Box Culverts

The purpose of slope tapered box culverts is to reduce construction costs by using a smaller barrel but still providing acceptable hydraulic capacity and upstream headwater. These special inlets have been used in Iowa and across the country since the 1950's or earlier. Successful use of these inlets requires careful hydraulic design and good construction practice.

The culvert site normally will meet two basic requirements to qualify for a tapered inlet. The first is that the additional design costs are offset by the reduction in construction costs. The second is that the site must have enough fall for the design to perform properly, typically at least six to eight feet.

The culvert inlet is made large enough to keep the depth of water at the entrance within allowable limits. The slope tapered section funnels the water down a steep slope as the culvert width decreases. The barrel section is designed to flow nearly full when carrying the design discharge. Generally, the outlet has a flume and basin for energy dissipation.

Design Steps

There are five basic steps for the hydraulic design a box culvert with a slope tapered inlet:

1. Determine the design discharge. Refer to Appendix J for guidance. The Iowa Runoff Chart may be used for rural watersheds draining 1280 acres (518 hectares) or less.
2. Determine the allowable depth of water at the inlet. Typically, the Iowa DOT allows one foot (0.3 m) of water above the top of the inlet.
3. Select an inlet size that results in a flow depth less than or equal to the allowable. Inlet control nomographs from FHWA's "Hydraulic Design of Highway Culverts," HDS No. 5, can be used for this.
4. Select a barrel size and slope that results in the barrel flowing less than full. The barrel height should be the same as the inlet, while the barrel width should generally be no less than 50 to 60% of the inlet width. Select a slope steep enough to maintain supercritical flow. Charts in FHWA's "Design Charts for Open-Channel Flow", HDS No. 3, have been developed from Manning's equation and can be used to select the appropriate slope.
5. Determine the drop and length of the slope tapered section. The minimum drop needed is the specific energy at the inlet (H_1) minus the specific energy at the barrel (H_2) plus energy losses (H_L). Specific energy is the depth plus velocity head at a given location.

The following guidelines, charts and worksheets (English and metric units) are provided to assist in the hydraulic design.

When the inlet will be raised significantly to create a pond, geotechnical concerns must be considered to ensure that seepage through the embankment is not excessive.

General Guidelines

1. HW from inlet control charts for proposed inlet size, no greater than D + 2 ft (0.6 m).
2. The height (D) of the structure does not change.
3. Calculated Z may be rounded to the next higher increment as described below. Minimum Z = 3 ft. (0.9 m).
4. Taper can be designed by using the RCB standard reinforced steel pattern of inlet size for the entire length of the taper and varying the length of the transverse steel.
5. The barrel outlet flow line is usually set at least ½ (D) above streambed. This prevents the barrel from "drowning out".
6. The outlet usually has a flume with a basin that is buried 4 to 6 ft. (1.2 to 1.8 m) below streambed, to help dissipate energy.
7. The barrel slope (S_o) should generally be 1.5% or steeper in order to maintain supercritical flow and the maximum flow depth of 0.9D in the barrel. See "Design Charts for Open Channel flow," HDS No. 3, FHWA, to determine specific flow depths for various slopes.
8. An attempt should be made to design barrel sizes to conform with standard RCB sizes. This may mean starting with a "wide" non-standard inlet.
9. Assume energy loss, H_L = 0.2 ft. (0.1 m) for all cases.

Guidelines for single RCBs

1. Use drop rate (L/Z) of approximately 3: 1.
2. Ratio of barrel width to inlet width (B_2/B_1) should be 50% or greater.
3. For Z=3ft., use L=10ft. For Z=4ft., use L=12ft. For Z=5ft., use L=15ft.
   (For Z=0.9m, use L=3.0m. For Z=1.2m, use L=3.6m. For Z=1.5m, use L=4.5m)

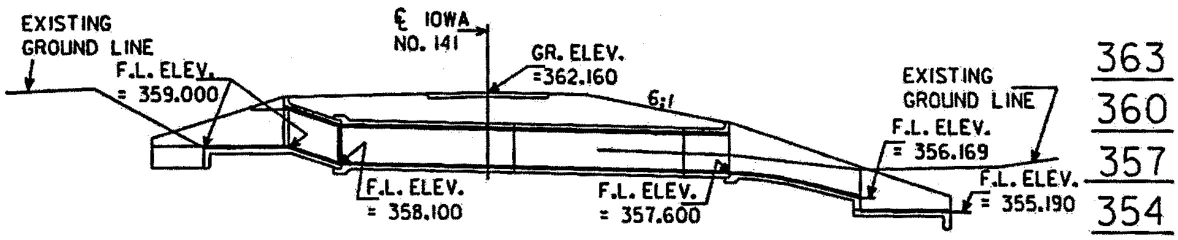
Guidelines for Twin RCBs

1. Use drop rate (L/Z) of 5:1 (min.).
2. Ratio of barrel width to inlet width (B_2/B_1) should be 60% or greater.
3. L is determined either by (B_1 - B_2) x 4 or Z x 5, whichever is greater. This insures a minimum side taper of 4:1. L should generally be in 5 ft. (1.5 m) increments.

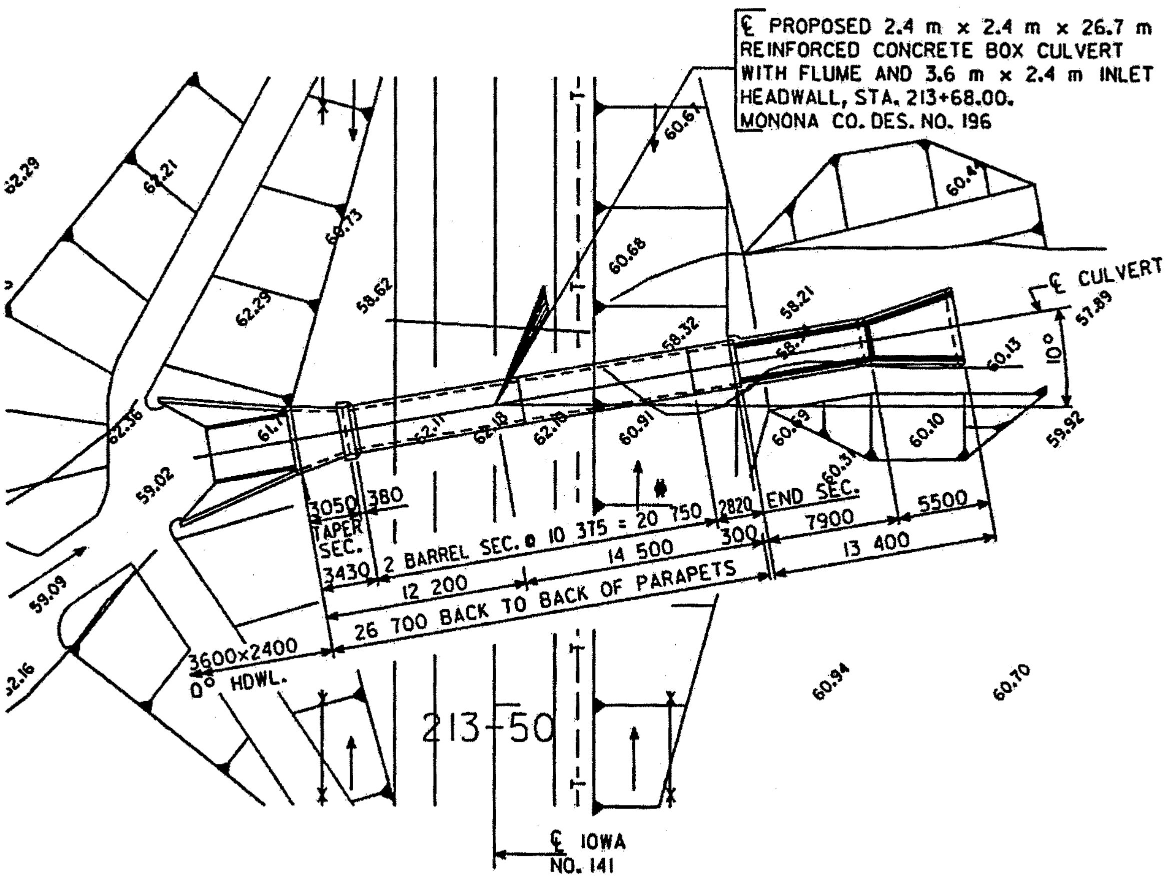
Definitions

HW = Headwater from inlet control charts
H_1 = Specific energy head at inlet
H_2 = Specific energy head at barrel
B_1 = Width of inlet opening
B_2 = Width of barrel opening
D = Height of opening
H_L = Energy loss
d_c = Critical depth
Z = Drop in flow line required
L = Length of taper section
S_o = Slope of barrel
$V^2/2g$ = Velocity head
N = L/Z = Slope of taper section

Sample Slope Tapered Box Culvert and Flume

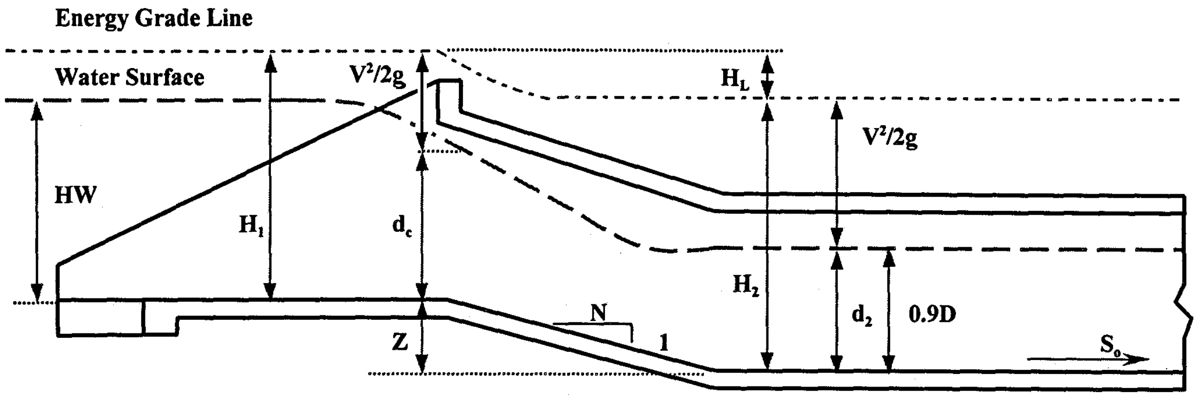


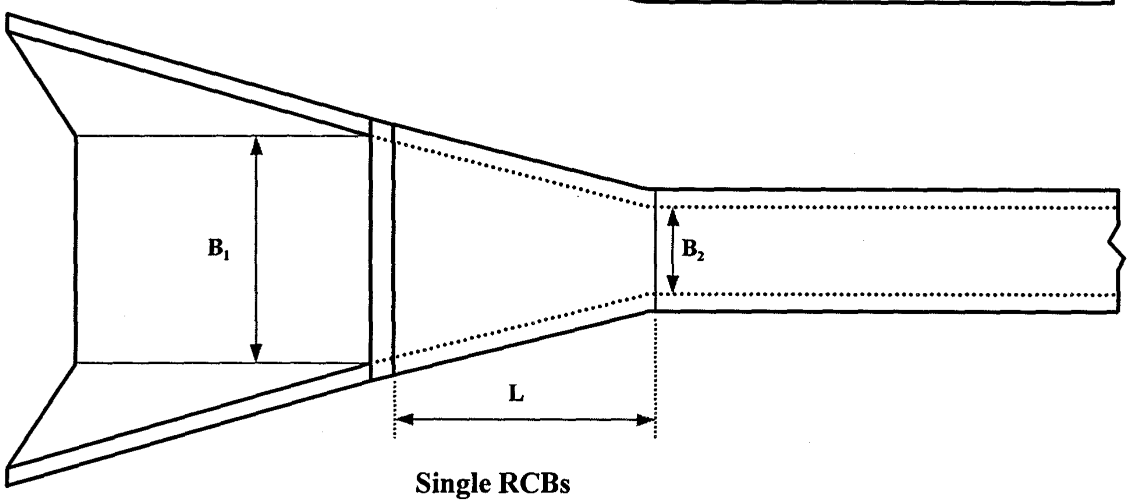
LONGITUDINAL SECTION ALONG ℄ CULVERT



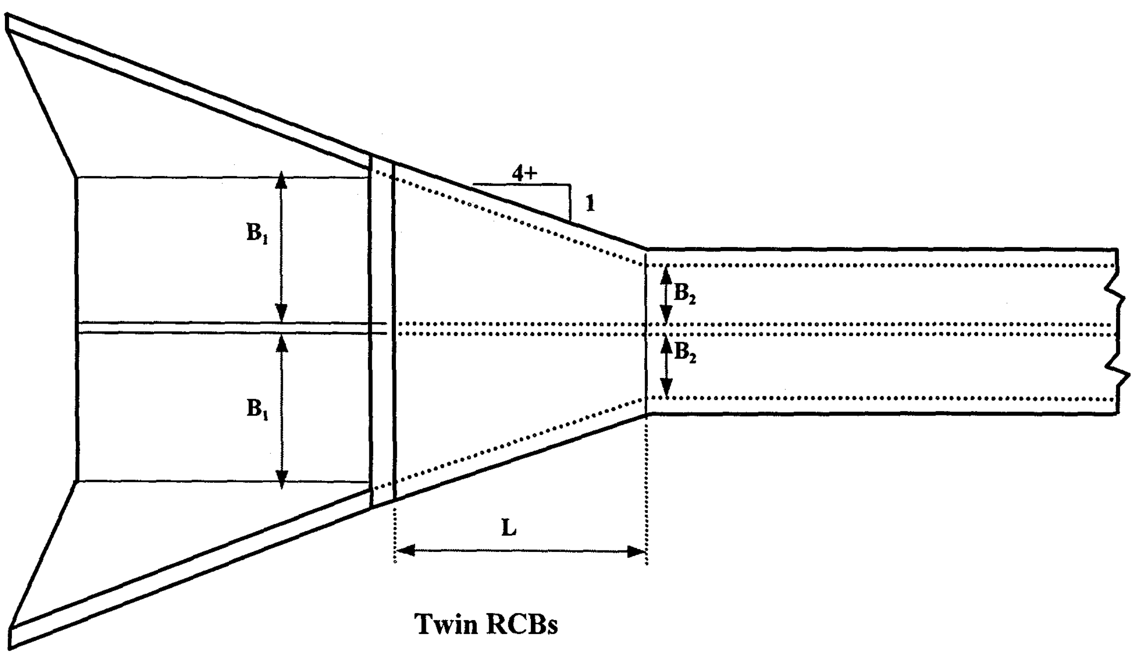
SITUATION PLAN

Slope Tapered Box Culverts





Single RCBs



Twin RCBs

Worksheet for Slope Tapered Box Culverts (English)

Project ______________________ County ______________________ Date ______________
Station ______________________ Designer ______________________

Variable	**Example**	**Trial 1**	**Trial 2**	**Trial 3**	**Trial 4**
Design Q, ft^3/sec	600				
Inlet Section					
B_1 x D, ft. x ft. (size of inlet)	10 x 6				
Q/ B_1	60				
HW, ft. (from HDS No. 5 nomographs)	7.5				
d_c, ft. (from design graph)	4.8				
H_1, ft. (from design graph)	7.2				
Barrel Section					
B_2 x D, ft. x ft. (size of barrel)	6 x 6				
Q/ B_2	100				
0.9 x D, ft.	5.4				
H_2, ft. (from design graph)	10.7				
Slope Tapered Section					
H_L, ft. (assumed)	0.2	0.2	0.2	0.2	0.2
Z, ft. ($= H_2 - H_1 + H_L$)	3.7				
Selected Z, ft.	4.0				
Selected L, ft.	12				
Barrel Slope					
d_n = 0.9 x D, ft.	5.4				
Min. slope, % (from HDS No. 3 or Manning's eqn.)	1.5				
Is the design acceptable?	Yes				